Comparison of System-Level Impact of Multi-Junction, Gallium Arsenide, and Silicon Solar Cells

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Agenda

- Summary of Space Solar Cell Types
- Introduction to Multi-Junction Cell Technology
- Comparison of Cell End-of-Life Performance for Different Cell Types
- Comparison of Array Performance for Different Cell Types
- Calculation of System-Level Effects of Using Higher-Efficiency Solar Cells
- Results of Calculation for Large, Medium, Small Spacecraft
- Conclusion

Types of Space Solar Cells

- Silicon solar cells
  - –up to 15% efficient*

- Gallium Arsenide on Germanium solar cells
  - –approximately 18.5% efficient*

- Two-Junction Cascade solar cells
  - –up to 24% efficient*

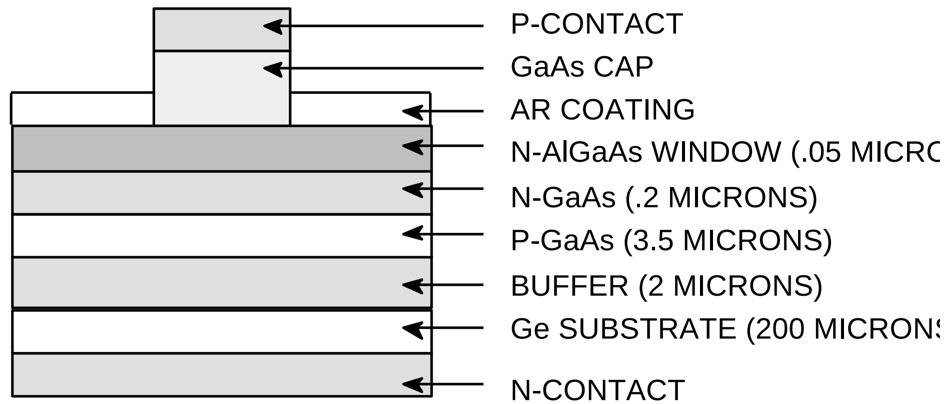
- Three-Junction Cascade solar cells
  - –up to 27% efficient*
  - (not yet achieved in production-25.7% achieved on small quantities of cells)

* at 28 degrees C, 1 Sun Air-Mass Zero (AM0)

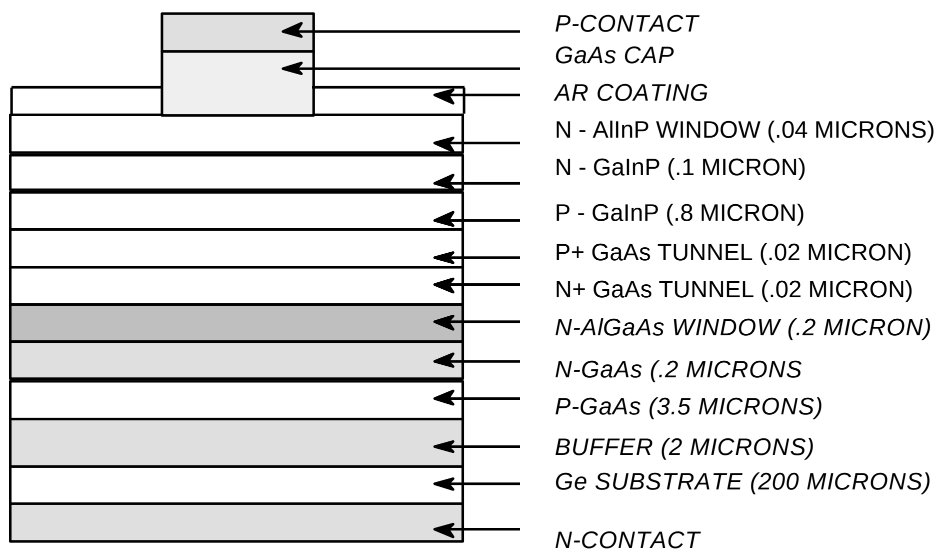
What are Multi-Junction Solar Cells?

- Consist of two or more cells, one stacked on top of the other, either mechanically or via MOCVD growth
  - The cells each have a different bandgap energy to take advantage of different light wavelengths
- Results in the conversion of a greater portion of the solar spectrum to electricity, increasing cell efficiency

Cross-Sections of Gallium Arsenide on Germanium and Dual-Junction Solar Cells



Gallium Arsenide on Germanium Solar Cell



Two Junction Cascade Solar Cell

Advantages of Multi-Junction Solar Cells

- For a given power requirement, a smaller array area (and weight) is required than for GaAs/Ge or Si arrays.
- A given array area can support a greater payload than GaAs or Si arrays of the same area.

Definitions Of Terms in Equations

- WEIGHTS OF:
  INSTR = SCIENCE PAYLOAD
  DATA = C&DH SUBSYSTEM
  COMM = COMMUNICATIONS SUBSYSTEM
  ELEC = ELECTRICAL SUSSYSTEM
  PWR = POWER SUBSYSTEM
- CF = FRACTION OF C&DH SUBSYSTEM USED TO SUPPORT SCIENCE
- PF = FRACTION OF POWER USED BY INSTRUMENT IN NORMAL OPERATION
- SF = FRACTION OF WEIGHT OF SOLAR ARRAY THAT CHANGES WHEN ARRAY POWER CAPABILITY CHANGES

Summary of Results

- Cost per Unit Weight to Launch and Support a Spacecraft Payload is about:

  600 K$/Kg

- Cost Per Unit Weight to "Buy" Additional Payload with GaAs & MJ Cells is respectively:

  152 K$/Kg to 500 K$/Kg

  127 K$/Kg to 253 K$/Kg

Computations Made For:

- A Large Size, 11,000 Kg, Spacecraft with a Tracking Blanket Array.
  - Used as an example throughout most of this presentation
- A Medium Size, 3,500 Kg, Spacecraft with a Tracking Rigid Array
- A Small Size, 240 Kg, Spacecraft with a Fixed Rigid Array

Si, GaAs & MJ Cell Performance Summary for for a Five Year Blanket Array

Cell Type	*EOL Efficiency*	*Cost/cm²*
Silicon	7.0%	$1.25
Thin Silicon	7.8%	$2.08
Gallium Arsenide	11.8%	$20.38
Multi-Junction	16.0%	$26.04

Costs are Estimated on the High Side for the GaAs and MJ Cells

Si, GaAs & MJ Array Performance Summary for a Five Year 5,000W Blanket Array

Attribute	*Si*	*Thin Si*	*GaAs*	*MJ*
Array Area (m^2)	59	52.9	35	25.8
Cell Weight (Kg)	36.7	14.5	32.3	23.8
Blanket Weight (Kg)	102.1	73.8	72	53.6
Total Weight (Kg)	233.2	199.9	180.2	151.5
Cost (M$)	28	29.5	38	33.3

Methodology to Compute Value of Saved Weight

- One evaluation of array cost effectiveness is based on launch cost:
  - about $11K/Kg for LEO spacecraft.
- Another is based on launch cost and spacecraft spacecraft support costs to the payload:
  - about $600K/Kg
  - this evaluation is used in this work

Methodology Consequences

- Using the selected methodology means that weight is taken out of the solar array and is added to the spacecraft payload e. g. the scientific instrument.
- All of the weight taken from the array cannot go into the payload because the increase in instrument weight forces some spacecraft subsystems to increase in capability and weight.

Spacecraft Subsystems Not Affected by Weight Transfer from Solar Array to Payload

- Structural
- Attitude and Control
- Thermal
- Propulsion

Spacecraft Subsystems Affected by Weight Transfer from Solar Array to Payload

- Electrical
- Power
- C & DH
- Communications

Computation of Payload Weight Increase from GaAs to MJ Blanket Array for a Large Spacecraft

28.7 Kg Difference Between the GaAs and the MJ Array

CF*DATA (28.7-²DATA-²COMM-²PWR-²ELEC-²SA)/INSTR = ²DATA

CF*COMM (28.7-²DATA-²COMM-²PWR-²ELEC-²SA)/INSTR = ²COMM,

PF*ELEC (28.7-²DATA-²COMM-²PWR-²ELEC-²SA)/INSTR = ²ELEC,

PF*PWR (28.7-²DATA-²COMM-²PWR-²ELEC-²SA)/INSTR = ²PWR,

SF*PF*SA (28.7-²DATA-²COMM-²PWR-²ELEC-²SA)/INSTR = ²SA,

INSTR = 1163.3 kg; DATA = 369.7 kg; COMM = 204.1 kg; ELEC = 294.8 kg;

PWR = 427.6 kg; SA = 151.5 kg; CF = .9; PF = .457; SF = .863

Solving these equations yields the following results:

²DATA = 4.61 kg,

²COMM = 2.55 kg,

²ELEC = 1.87 kg,

²PWR = 2.71 kg,

²SA = .83 kg,

Total = 12.57 kg.

Summary of Calculations

- Compute Cost Saved by Advanced Cells
  - Compute How Much Weight Advanced Cells Save on the Solar Array.
  - Compute How Much of the Above Weight Can Go Into the Spacecraft Payload.
  - Estimate the Cost/Kg of Launching and Servicing the Spacecraft Payload and Multiply by the Additional Payload Weight.
- Compute Additional Costs of Advanced Cells
  - Estimate Additional Array Costs
  - Estimate Additional Spacecraft Costs Including a More Powerful Array
- Compare Savings to Additional Costs

Performance Summary for Large Size Spacecraft

	Si	Thin Si	GaAs	MJ
K$/Kg to Launch & and Support Payload	605	598	602	591
Payload Weight (Kg)	1134	1152	1163	1179
K$/Kg that High Perf. Cells "Buy"	N/A	216	500	253

Performance Summary for Medium Size Spacecraft

	Si	GaAs	MJ
K$/Kg to Launch & and Support Payload	552	531	519
Payload Weight (Kg)	633	664	678
K$/Kg that High Perf. Cells “Buy”	N/A	152	127

Performance Summary for Small Size Spacecraft

	Si	GaAs	MJ
K$/Kg to Launch & and Support Payload	680	641	617
Payload Weight (Kg)	58.2	62.4	64.9
K$/Kg that High Perf. Cells "Buy"	N/A	189	164

Cautions

- Analysis Presumes a Clean Possibility to Plan the Spacecraft
- S/C Weight Becomes More Critical as the S/C is About to Need a Larger Launcher
- Subsystems are Frequently not Fully Optimized to Get Subsystem Heritage
- One of a Kind Spacecraft Carry Large Weight Contingencies
- Analysis not Immediately Compatible with GSFC Costing